Development of a UGV-Mounted Automated Refueling System for VTOL UAVs

Katherine Mullens[a], Aaron Burmeister[a], Mike Wills[a], Travis Nelson[a], Thomas Denewiler[b]

[a] Space and Naval Warfare Systems Center San Diego, 53560 Hull Street, San Diego, CA 92152-5001
[b] SAIC, 3990 Old Town Ave., Ste. 304C, San Diego, CA 92110

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ABSTRACT

This paper describes the latest efforts to develop an Automated UAV Mission System (AUMS) for small vertical takeoff and landing (VTOL) unmanned air vehicles (UAVs). In certain applications such as force protection, perimeter security, and urban surveillance a VTOL UAV can provide far greater utility than fixed-wing UAVs or ground-based sensors. The VTOL UAV can operate much closer to an object of interest and can provide a hover-and-stare capability to keep its sensors trained on an object, while the fixed wing UAV would be forced into a higher altitude loitering pattern where its sensors would be subject to intermittent blockage by obstacles and terrain.

The most significant disadvantage of a VTOL UAV when compared to a fixed-wing UAV is its reduced flight endurance. AUMS addresses this disadvantage by providing forward staging, refueling, and recovery capabilities for the VTOL UAV through a host unmanned ground vehicle (UGV), which serves as a launch/recovery platform and service station. The UGV has sufficient payload capacity to carry UAV fuel for multiple launch, recovery, and refuel iterations. The UGV also provides a highly mobile means of forward deploying a small UAV into hazardous areas unsafe for personnel, such as chemically or biologically contaminated areas. Teaming small UAVs with large UGVs can decrease risk to personnel and expand mission capabilities and effectiveness.

There are numerous technical challenges being addressed by these development efforts. Among the challenges is the development and integration of a precision landing system compact and light enough to allow it to be mounted on a small VTOL UAV while providing repeatable landing accuracy to safely land on the AUMS. Another challenge is the design of a UGV-transportable, expandable, self-centering landing pad that contains hardware and safety devices for automatically refueling the UAV. A third challenge is making the design flexible enough to accommodate different types of VTOL UAVs, such as the AAI iSTAR ducted-fan vehicle and small helicopter UAVs. Finally, a common command-and-control architecture which supports the UAV, UGV, and AUMS must be developed and interfaced with these systems to allow fully autonomous collaborative behaviors.

Funded by the Joint Robotics Program, AUMS is part of a joint effort with the Air Force Research Laboratory and the Army Missile Research Development and Engineering Command. The objective is to develop and demonstrate UGV-UAV teaming concepts and work with the warfighter to ensure that future upgrades are focused on operational requirements.

This paper describes the latest achievements in AUMS development and some of the military program and first responder situations that could benefit from this system.

I. INTRODUCTION

Small VTOL UAVs can be valuable tools for both the warfighter and the first responder in providing assessment of an operational situation. They can fly at various altitudes, hover over specific areas for a steady view of an unfolding situation, and autonomously launch, land, and re-launch without need of a bulky launcher or a long runway.

Small VTOL UAVs are typically represented by helicopters, tilt-rotor designs, and lift-augmented ducted-fan (LADF) vehicles. The LADF vehicles are particularly appealing due to their small footprint, scalability, and the safety provided by the duct around the rotor. In addition to enhancing thrust, the duct tends to protect the rotor from ingesting foreign objects as well as protecting personnel from accidental contact with the spinning rotor.

The Army's Future Combat Systems (FCS) program, the Army's major effort to "fundamentally transform into a faster, more agile force with superior situational awareness and power projection capability," is spurring development of small UAVs [1]. In the FCS vision, these small UAVs are categorized as Class I and Class II. The Class I UAV will weigh 15

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pounds or less and is intended to provide the dismounted soldier reconnaissance, surveillance, and target acquisition (RSTA). A VTOL representative of this class is the DARPA Micro Air Vehicle (MAV), an LADF design with a 13" diameter duct. [2]

The Class II UAV is a VTOL design with twice the endurance and a wider range of capabilities than the Class I. Another term frequently used to describe this class of vehicle is the Organic Air Vehicle (OAV). It will provide reconnaissance, security/early warning, target acquisition and designation to company commanders, and can be launched from vehicles and provide line-of-sight (LOS) enhanced digital imagery. The Class II UAVs, capable of teaming with selected ground and air platforms and providing limited communications relay capabilities, will be small enough to be carried by no more than two soldiers. A representative example of a Class II UAV is the AAI 29 inch iSTAR.

Fig. 1. Examples of FCS Class I (left - MAV) and Class II (right) UAVs

These types of UAVs have several characteristics that can restrict their adoption by a wide range of users. Their payload capacity is limited, which results in an operational tradeoff between desired payload capabilities and mission duration. These UAVs may spend little time in their area of operation due to limited endurance and the frequent need to return to base for refueling. Limited endurance and range inhibits the ability of these vehicles to perform some missions, reducing their overall effectiveness. One alternative is to place the UAV and its support personnel closer to hazardous conditions.

In order to increase the effectiveness and meet the requirements for future military operations, Space and Naval Warfare Systems Center San Diego (SSC San Diego) has developed the Autonomous UAV Mission System (AUMS). This system utilizes technologies developed at SSC San Diego and other research institutions to autonomously launch, land, and refuel VTOL UAVs. AUMS is designed for use with Class II LADF UAVs but is scalable and adaptable for any VTOL UAV. The system can be located on a mobile platform such as a manned vehicle or a UGV, or it can be utilized as a stand-alone autonomous base of operations at a fixed location. This reduces the exposure of operations and support personnel to hazardous environments while increasing the utility and impact of the UAV.

2. AUMS TECHNICAL DEVELOPMENT

The AUMS technical development is divided into four major phases: Launch, Recovery, Refueling, and Command and Control (C2). Each phase utilizes a common set of technologies and builds upon previous technical accomplishments. Initial AUMS design and development has focused on use with the AAI iSTAR 29i UAV platform (Fig. 2), an LADF design that fits the definition of an FCS Class II UAV. It is capable of autonomous vertical takeoff and landing as well as high-speed horizontal flight. Payloads may be carried in the nose, duct, or tail section of the iSTAR. [3]

Fig. 2. AAI 29 inch iSTAR UAV

In addition to the iSTAR, SSC San Diego is currently using a variety of tele-operated and autonomous helicopters as low-cost technology development surrogates for the iSTAR platform. An example is the SR100 autonomous helicopter developed by Rotomotion, LLC (Fig. 3). The helicopters are modified for use with AUMS by incorporating ring-shaped landing gear similar to the one found on the iSTAR platform. This landing gear is equipped with the AUMS refueling coupler to allow test and development of all of the AUMS functional capabilities. The helicopters are also used to test cameras and other payloads, as well as AUMS command and control software [4]. Future AUMS development will utilize other FCS Class II VTOL UAVs.

Fig. 3. Rotomotion Helicopter

2.1. LAUNCH

Initial development of the AUMS project began in 2002 at SSC San Diego with the fabrication of a basic fiberglass prototype launch fixture. This solenoid-actuated device was mounted on a Mobile Detection Assessment Response System (MDARS) UGV and tested with the iSTAR at an airstrip in Holtville, Ca. MDARS was designed to provide intruder detection and assessment, barrier (lock status) assessment, and inventory accountability at military depots. MDARS represents an appropriately sized UGV for the types of missions anticipated for AUMS with the iSTAR UAV.

The prototype launch fixture secured the UAV utilizing a simple hook controlled by a solenoid which engaged the lower center body of the UAV. [5] The latch proved useful in keeping the UAV secure while the UGV was in transit. In addition the latch allowed the UAV to reach full power before taking off reducing the effects of cross winds.

In 2003, a second AUMS prototype was developed and demonstrated with the iSTAR, incorporating a passive self-centering mechanical device (Fig. 4) that coupled with the UAV for refueling, launch, and transport. After the UAV lands, a linear actuator elevates the refueling/capture mechanism to mate with a coupler installed on the UAV. The centering mechanism incorporates a passive cone that is free to move laterally (up to an inch) to accommodate slight misalignment.

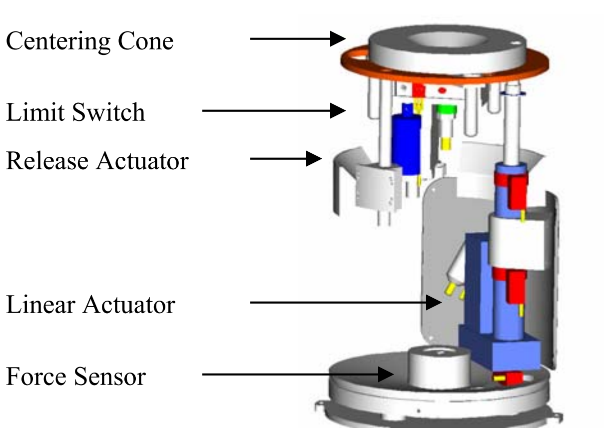

Fig. 4: Refueling/Release Centering Mechanism

The coupler serves dual functions. It provides a method of latching and securing the UAV to AUMS and it also serves as the fluid path for refueling and defueling operations. The coupler and the AUMS hardware configuration make the system independent of UAV heading. The UAV can be rotated to any heading and the centering mechanism will still function as designed. After successfully coupling, the actuator is lowered to apply tension to the UAV, seating the UAV firmly on the landing pad. Tension forces are measured by the force sensor located in the base of the mechanism to confirm a positive coupling.

The standard AUMS-UAV launch procedure is to develop full UAV thrust prior to release. The force sensor in the AUMS base measures the thrust generated by the UAV prior to launch to determine if the UAV is producing sufficient thrust for a safe takeoff. This technique ensures the UAV is at full takeoff thrust before it is released and begins to ascend. When the UAV reaches its maximum thrust, a release solenoid activates the outer collar of the fuel coupler and releases the UAV. This approach maximizes acceleration, minimizes its exposure to the area containing antennas and sensors on the UGV, and the UAV minimizes the time spent at low velocities. This technique is similar to short field takeoff procedures used with fixed wing aircraft which involve holding the aircraft in place with brakes while the engine is brought to full power.

The second prototype tested a variety of moveable arms that could be configured like a launch tube or expanded to increase pad circumference for landing (Fig. 5). It was thought that these arms could help guide the UAV as it accelerated during launch. The arms were found to interfere with the UAV's ability to land safely and also created a hazard for launch so the arms were ultimately eliminated from the design.

Fig. 5. 2nd prototype with reconfigurable arms.

A third prototype was built in 2004 without the actuated arms (Fig. 6), and tested both solid and vented landing surfaces to determine how ground effect might influence takeoff and landing performance. It was determined that the solid pad had no measurable effect on takeoff performance but had a negative effect on UAV handling when in close proximity to the pad during landings. Future systems will use vented pads. This prototype was also used for further testing and development of the refueling system.

Fig.6. iSTAR performing a teleoperated tethered landing on the third AUMS prototype.

A fourth prototype was developed in late 2005, which incorporated all lessons learned from previous testing and added the planned mechanics to actively center the UAV on the AUMS. The autonomous centering mechanism actively centers the UAV on the landing pad allowing the refueling mechanism to mate with the UAV. The refueling mechanism is designed to permit minor misalignment that has not been corrected by the centering mechanism. This centering mechanism will be described in detail in section 2.2.2. The launch technology remains the same as in the previous prototype.

2.2. RECOVERY

The development of the recovery system has two major subcomponents. The first is the precision landing capability of the UAV. The second is the automated capturing and centering mechanism that moves the UAV to the proper position for refueling, transport by the UGV, and relaunch.

2.2.1. PRECISION LANDING

The ability to precisely land an autonomous VTOL UAV on a UGV-mounted landing pad requires very accurate positioning technology. The required landing surface will vary, depending on the size of the UGV and UAV as well as landing gear configuration. The maximum landing pad diameter compatible with the MDARS UGV is 48 inches as anything larger interferes with communications and GPS antennae and other sensors located on the MDARS top deck.

The UAV must be capable of very precise three-dimensional navigation in order to ensure accurate repeatable landings with extremely low position error relative to the fixture. Furthermore, this relative-position solution must be updated at high rates to account for UAV dynamics as well as environmental factors affecting the UAV approach and landing [6]. There are two factors to consider. The first is the precision of the sensors used in determining where the UAV is relative to AUMS. The second factor is the ability of the UAV to be accurately servo controlled to the desired position in space, and to then maintain that position based on the feedback from those sensors.

Various sensor technologies have been examined by SSC San Diego for use in developing this capability: real-time kinematic (RTK) differential GPS from Novatel; a highly accurate, relative positioning GPS technology using low-cost receivers from Geodetics, Inc; a vision-based positioning system that relies on near-infrared beacons arranged in an asymmetrical pattern on the UGV from Carnegie Mellon University; and a small, lightweight, vision-based target tracking and landing algorithm from University of Southern California [7, 8, 9, 10]. Currently SSC San Diego is evaluating a low cost near-infrared based system called NorthStar produced by Evolution Robotics. The system was designed for localization

within an enclosed space utilizing a fixed projector and a detector on the moving object. Current testing of the system will evaluate the use of this technology in an out door precision landing application. Testing aims to prove whether this system can be used to provide a UAV with six degree of freedom position relative to a landing pad. The tests are configured with two beacons on the landing pad and the sensor on the UAV.

SSC San Diego has also evaluated government-developed systems such as the Joint Precision Landing System (JPALS), which is the military equivalent of the Local Area Augmentation System (LAAS) currently used for civilian aircraft. JPALS utilizes differential GPS and a ship-based GPS master station to provide highly accurate aircraft landing capabilities, but is currently too large and expensive for use with AUMS. It also requires a GPS correction signal which may not be available in a dynamically changing ground-based environment. [11]

There are several challenges associated with integrating a precision landing capability with AUMS. One major problem is the lack of commercial-off-the-shelf solutions that meet the weight and size requirements. Another concern is that the solutions or technologies that could be utilized require significant investments of time and resources to mature them into easily reproducible, modular deliverables that are easy to integrate onto the UAV. And while there are a variety of UAVs and missions that could utilize AUMS, there are also a wide variety of potential landing requirements. This makes it difficult to determine the level of precision that is necessary. Accordingly, SSC San Diego continues to work with technology developers and users to identify and test various technology approaches that can be combined with project resources to achieve a practical solution.

The ultimate solution will likely merge multiple strategies, for example GPS for coarse localization and a vision-based or near-infrared solution once the UAV gets near the landing target where simple GPS may lack the required precision.

2.2.2. UAV CAPTURE

Even though the UAV has a precision landing capability that allows repeatable safe landings on the 48-inch platform, it may not land close enough to center for the passive centering mechanism to capture the UAV coupler. The AUMS must therefore incorporate a mechanism to position the UAV on the center of the platform over the refueling nozzle. The current design (Fig. 7) uses four levers that actuate independently to move the UAV into the proper position. These levers incorporate sensors to provide feedback on the movement of the UAV to ensure correct positioning, and to detect if the UAV has somehow gotten hung up during the centering operation. In the extended position, the levers are located below the landing surface to ensure that they do not interfere during the landing process. This design was completed in November 2005, and has been tested with a static iSTAR UAV in various positions on the pad. It will be further evaluated over the next several months with teleoperated helicopters and the iSTAR to determine whether further modifications need to be made.

Fig. 7. AUMS with UAV-centering levers.

2.3. REFUELING

Automated refueling allows the UAV base of operations to be moved into a hostile or contaminated environment while reducing impact on human personnel. Currently there are no turnkey solutions for automated refueling of small UAVs. SSC San Diego engineers designed the AUMS to fill this void.

In order to address the inherently dangerous task of refueling a UAV with hydrocarbon fuel, steps were taken to increase safety utilizing software, electrical, and mechanical design elements.

AUMS software utilizes a fault-tolerant system of sensors that return latch and refueling status messages to the command and control software. This system detects and reacts to UAV coupling and positioning errors that could result in an unsafe environment for refueling. Failsafe modes allow these independent, often redundant sensor arrays to individually put the system into a safe state. To further ensure safe operation, all flow control solenoids default to a normally closed state such that in the case of complete power failure, the fuel lines would become sealed. To increase safety, all the components that cause fuel to flow and all the components that cause the UAV to be released were chosen and integrated so that their non-energized default state is closed. This was done to prevent a loss of power, a computer glitch or some other unforeseen condition from creating a situation that could harm people or equipment. In addition, the use of normally-off components reduces power consumption and radiant heat generated by energized devices such as solenoids and relays.

Mechanical safety features include a fluid coupler utilized to link the UAV to AUMS incorporating a spill proof passive sealing mechanism on both sides of the coupler interface. No fuel can leak from either side of the coupler when the two pieces separate. The refueling module and the AUMS landing platform incorporate sumps with optical sensors located at the bottom of the sump. A fuel leak within the refueling module, from the UAV, or on the platform will drain to the sump. When the liquid fuel contacts the optical sensor at the bottom of the sump, the system shuts down and goes into safe mode. For redundancy, the flow rate on the refueling module can be compared with the flow rate monitored on board the UAV (if the UAV is flow-rate-sensor equipped) to detect any leak that the optical sensors fail to catch, such as a leak in the fuel line between the refueling module and the AUMS platform. The AUMS platform and the refueling module incorporate separate fire suppression systems that utilize tubing charged with a fire retardant (FM-200). In the event of a fire, this tube will melt and locally distribute the fire retardant. The system micro-controller is signaled upon release of the retardant and puts the system into safe mode. Exposed fuel line is armored to protect against accidental rupture and Mil-Spec-type fluid couplers are utilized for all fuel system connections.

Commercial-off-the-shelf (COTS) products such as intrinsically safe zener barriers were used to electrically isolate fuel components from electronics. When intrinsically safe components were not available, additional hardware was put in place to detect potentially dangerous situations.

The AUMS is designed to operate without knowledge of the current fuel level of the incoming UAV. Many, if not all, small UAVs do not have fuel gauges. Typically flight endurance is estimated based on known fuel consumption rates for various phases of flight and measured time aloft. As a result, the most reliable means of accurately refueling with a known quantity of fuel is to first de-fuel the UAV. This not only allows precise calculation of fuel needed to fill the UAV, it allows for partial refueling trading fuel weight for payload capacity to suit the mission. By incorporating a bidirectional pump, AUMS completely de-fuels and then refuels the UAV to the desired level. A flow meter is integrated in the AUMS fuel line to the UAV to provide feedback to the AUMS electronics system.

Fig. 8. AUMS refueling module with IStar installed on MDARS.

The refueling section of the AUMS (i.e. the electronics, fuel reservoir, pump, and filter) is modular in nature and is housed in a single case. This module uses a capacitive level sensor in the fuel reservoir as well as a flow sensor to monitor

refueling status. The module incorporates a standardized payload mount developed for attaching a variety of different types of payloads to the MDARS vehicle (Figs. 8 and 9). A frame with keyholes is installed on the rear of the MDARS vehicle, and all compatible payloads have brackets with corresponding circular keys attached. When mounted, the payloads are constrained from motion in all directions. Support legs can be attached to the payload mount on the refueling module for stand-alone applications. The module case and electrical connectors are weather-proof and will tolerate light rain and blowing dust.

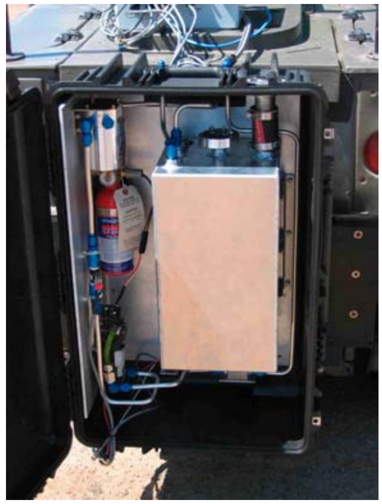

Fig. 9. AUMS Refueling Module with access door opened

The AUMS electronics system includes embedded microprocessors for control of the actuators and sensors, 802.11 wireless access for network communications, and the various actuators, pump, and feedback sensors. In addition, sensors can be integrated on the UAV (such as fuel level, fuel flow sensors, etc.) for enhanced performance, although these UAV-mounted sensors are not required for AUMS operation.

There is strong interest on the part of UAV users for their vehicles to be heavy-fuel compatible. There are numerous reasons for this, the most compelling being logistics and safety. With heavy fuel being the fuel of choice for aviation applications and the majority of ground systems in the military inventory, having to supply a custom fuel such as a gasoline-oil premix dedicated to UAV use is a major stumbling block. From a safety standpoint, having to store, transport, and utilize a highly volatile fuel like gasoline exposes UAV users and support personnel to undue risk, however, currently all the small UAVs that are using internal combustion engines are gasoline-oil premix fueled. At this point in time, technology has not produced a heavy-fuel engine of suitable size, weight, and power for these vehicles. Technology development on small heavy fuel engines is progressing rapidly and there should be small UAVs flying on heavy fuel in the near future.

The refueling system for AUMS was designed for use with gasoline-oil premix, since all of the UAVs tested with it to date are gasoline fueled. However, all hardware is heavy-fuel compatible and the system could be adapted to heavy-fuel after a simple recalibration of the sensors. The refueling system prototype was completed in August 2005 by SSC San Diego engineers and Office of Naval Research interns from University of California, San Diego.

2.4 COMMAND AND CONTROL

The AUMS system is compliant with the Joint Architecture for Unmanned Systems (JAUS), a Society of Automotive Engineers (SAE) recognized interface protocol standard developed specifically for use with unmanned systems. JAUS allows communication between different unmanned systems through a common language set and supports for autonomous interaction between dissimilar systems. JAUS has wide acceptance in the UGV arena and is gaining acceptance in the UAV, Unmanned Surface Vehicle (USV) and Unmanned Undersea Vehicle (UUV) communities as well. JAUS was recently announced as the interface protocol to be used by all unmanned systems associated with the Navy's Littoral Combat Ship (LCS).[12, 13]

AUMS utilizes the Multi-Robot Operator Control Unit (MOCU) software developed by SSC San Diego for command and control interface to a human operator (Fig. 10).[14] MOCU is also a JAUS-compliant system designed specifically for the purpose of controlling multiple heterogeneous unmanned systems simultaneously. MOCU has been utilized for the control of multiple UGVs of various sizes including MDARS, as well as much smaller man-portable systems, several USVs, and most recently a VTOL UAV. It also is capable of controlling and collecting data from a wide variety of stationary

unmanned systems and sensors, to include remotely operated weapons systems, radars, video systems, and seismic detectors. The MOCU graphical user interface can automatically configure itself appropriately for the vehicle, system, or sensor being queried at a given time.[14]

Fig. 10. MOCU - AUMS user interface

Utilized in a UAV/AUMS mission scenario, MOCU allows a single operator complete control over UAV mission planning, collection of UAV sensor data, UAV payload control, and UAV status (Fig. 11). It has the same capabilities and displays the same types of data for the UGV carrying AUMS. The operator can relocate the UGV to position AUMS wherever required to best support the UAV mission. The AUMS MOCU display provides complete control over defueling, refueling, capture, and release operations, and provides monitoring of system status. An overview display continuously provides high-level system status and position of all unmanned systems and sensors under MOCU control for enhanced operator situational awareness. The overview can be displayed on a map or on a geo-referenced aerial photo. Multiple UAVs and multiple AUMS can be displayed simultaneously allowing the operator to determine which AUMS to send a given UAV to for servicing depending on AUMS status and distance from the UAV.

A MOCU demonstration was conducted in December 2005 at SSC San Diego to display simultaneous collaborative operation and control of a USV, multiple UGVs, and UAV by a single operator.[15]

Fig. 11. MOCU - UAV user interface, overview and multiple vehicle status on the right

Future C2 development for AUMS will focus on more autonomy to allow the UAV to determine when it needs to be serviced, to select an appropriate AUMS for servicing, and to autonomously land, refuel, and resume its mission independent of operator intervention.

3. COLLABORATIVE ENGAGEMENT

SSC San Diego is working with the Air Force Research Laboratory (AFRL) at Tyndall Air Force Base and the Army Missile Research Development and Engineering Command (AMRDEC) at Redstone Arsenal on the Collaborative Engagement Experiment (CEE) sponsored by the Joint Robotics Program. CEE is a joint effort, started in early 2005, to develop and demonstrate collaborative engagement between unmanned systems. CEE is designed to provide the framework for developing and demonstrating collaborative behaviors for unmanned systems. Goals of this joint effort include definition of operational needs, development and integration of technology solutions, live and simulated experimentation, user involvement, and joint technical solutions. AUMS represents a key technology area for CEE, demonstrating collaborative behaviors between UGVs and UAVs while fulfilling an operational need by enhancing the effectiveness of small VTOL UAVs.

Contingent on funding, a Joint experiment to demonstrate target acquistion, tracking, and elimination by unmanned ground and aerial vehicles is planned for July of 2006, contigent on funding. [16]

4. AUMS APPLICATIONS

The operational use of AUMS is called for by several current programs, including FCS and the Family of Integrated Rapid Response Equipment (FIRRE) program. FIRRE is an advanced technology demonstration program intended to develop a family of affordable, scalable, modular, and logistically supportable unmanned systems to meet urgent operational force-protection needs and requirements worldwide. The near-term goal is to provide the best available unmanned ground systems to the warfighter in Iraq and Afghanistan. The overarching long-term goal is to develop a fully-integrated, layered force-protection system of systems for our forward-deployed forces that is networked with the future-force C4ISR systems architecture. The intent of the FIRRE program is to reduce manpower requirements, enhance force-protection capabilities, and reduce casualties through the use of unmanned systems. FIRRE could utilize AUMS as one of several unmanned systems that would create a portable in-theater security system. The AUMS in combination with UGVs and UAVs provide FIRRE a mobile beyond-the-fence-line sensor capability [17]. AUMS in a mobile or fixed site installation is ideal for limited range force-protection. It provides a base of operation from which a system operator can launch and recover a VTOL UAV, extending the eyes and ears as needed beyond the reach of stationary sensors typically used in these applications.

AUMS technology is also appropriate for first responder situations. It can be used for responding to a potential chemical or biological attack by providing eyes on the situation without exposing personnel to contamination. Mounted on a UGV, AUMS makes it possible to forward project what is normally a short-range UAV capability beyond its typical useful range. The automated refueling capability allows it to stay on station continuously without need for human intervention and possible contamination.

5. CONCLUSIONS

VTOL UAVs provide significant tactical value to the warfighter and first responder. Their operational flexibility and ability to hover and stare, and ability to operate closer to the action make them a great tool for assessment and decision-making. However, their limited payload capabilities and flight endurance reduces their effectiveness. AUMS is a system designed to increase the effectiveness of VTOL UAVs by mounting them on unmanned ground vehicles and automating the launch, recovery and refueling process. SSC San Diego has developed several prototype systems and conducted tests and experiments with a variety of VTOL UAV platforms. Future plans include analysis, development and integration of automated landing technologies, further integration of command and control capabilities using JAUS and MOCU interfaces, increased system autonomy, and further participation in Joint UGV-UAV experiments.

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